# Electricity

Free charge carriers in a vacuum
*Thomson tube*

## Assembling a velocity filter (Wien filter) to determine the specific electron charge

## Objects of the experiments

■ Structure of the velocity filter (Wien filter)

■ Determination of the specific electron charge

## Principles

In the Thomson tube the deflection of electrons in electric and magnetic fields can be investigated quantitatively. The superposition of an electric and a magnetic field allows the construction of a velocity filter (Wien filter).

In the Thomson tube all the electrons pass through a slit aperture behind the anode and tangentially hit a luminous screen with a cm grid which is set up at an angle to the path of the light., Here the electron beam becomes visible and allows quantitative analysis. At the outlet of the slit aperture a plate capacitor is set up where the electron beam can be vertically deflected in an electrostatic field. In addition, by means of a Helmholtz pair of coils, an external magnet field can be set up which also allows vertical deflection of the electron beam.

In the experiment a velocity filter (Wien filter) is set up. For the fixed anode voltage $U_A$ the voltage at the plate capacitor $U_P$ and the current through the Helmholtz pair of coils $I$ is selected in such a way that the deflections from the electric and the magnetic fields just cancel each other out at the outlet of the plate capacitor. If $U_A$ and therefore speed of the electron speed is changed, it is apparent that this compensation without a change of $U_P$ and $I$ is only possible at a speed of $v = \sqrt{\dfrac{2 \cdot e \cdot U_A}{m}}$ and that the electron beam is deflected once again. Only by changing $U_P$ or $I$ can the deflection be compensated for again.

In addition this setup allows more precise determination of the specific electron charge. When $U_P$ and $I$ are chosen in such a way that the electric and the magnetic field exactly compensate the specific charge is

$$\frac{e}{m} = \frac{1}{2\,U_A} \cdot \left(\frac{E}{B}\right)^2 . \qquad (1)$$

On account of the tube construction, the electric field is smaller than the value to be expected theoretically. This can be taken into account in the experiment by a correction factor:

$$E_{\mathrm{exp}} = 0{,}75 \cdot E_{theo} = 0{,}75 \cdot \frac{U}{d} . \qquad (2)$$
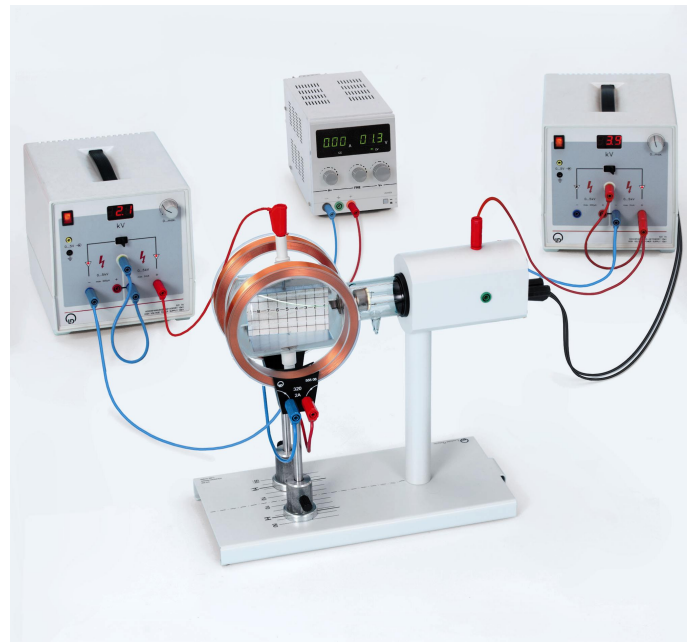


Fig. 1: Experimental setup

## Apparatus

| | |
|---|---|
| 1 electron deflection tube | 555 624 |
| 1 tube stand | 555 600 |
| 1 Helmholtz pair of coils | 555 604 |
| 2 high voltage power supplies | 521 70 |
| 1 DC power supply 0 – 16 V / 0 – 5 A | 521 545 |
| 2 safety connection leads, 25 cm, red | 500 611 |
| 1 safety connection lead, 50 cm, red | 500 621 |
| 1 safety connection lead, 50 cm, blue | 500 622 |
| 3 safety connection leads, 100 cm, red | 500 641 |
| 3 safety connection leads, 100 cm, blue | 500 642 |
| 2 safety connection leads, 100 cm, black | 500 544 |

The magnetic field $B$ can be calculated using

$$B = \mu_0 \cdot \left(\frac{4}{5}\right)^{\frac{3}{2}} \cdot \frac{N \cdot I}{R} \qquad (3)$$

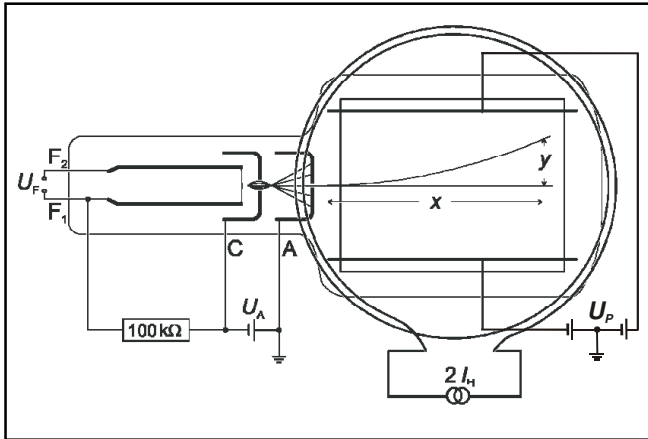with current $I$, number of windings $N$ and coil radius $R$. $d$ is the distance between the capacitor plates.

Fig. 2: Circuit diagram

## Safety note:

The Thomson tube is a thin-walled evacuated glass cylinder. Danger of implosion!

- Do not expose the tube to any mechanical loads.
- Connect the Thomson tube only by means of safety connection leads.
- Observe the operating instructions for the Thomson tube (555 624) and the tube stand (555 600).

## Setup

The experimental setup is shown in figure 1. The connections are also shown in figure 2. The 100 kΩ resistance is integrated in the tube stand (555 600). For setting up, the steps described below are required:

- Carefully insert the Thomson tube into the tube stand.
- Connect sockets $F_1$ and $F_2$ on the tube stand for the cathode heater to the 6.3 V output at the rear of the high voltage power supply 10 kV.
- Connect socket C on the tube stand (cathode cap of the Thomson tube) to the negative pole and socket A (anode) to the positive pole of the 10 kV high voltage power supply and in addition earth the positive pole.
- Place the Helmholtz pair of coils in the positions marked with H (Helmholtz geometry) on the tube stand. A deviation from the Helmholtz geometry will lead to systematic errors in the calculation of the magnetic field. For this reason such a deviation should be kept as small as possible. Adjust the height of the coils in such a way that the centres of the coils are aligned to the level of the beam axis.
- Connect the coils in series to the direct current power supply so that the current flows through the coils in the same direction. Ensure that the current flows in the same direction through the coils.
- Connect one capacitor plate to the positive pole at the right-hand output, the other to the negative pole of the left-hand output of the second 10 kV high voltage power supply and earth the middle socket of the high voltage power supply.

## Carrying out the experiment

- Measure the distance $d$ between the capacitor plates.
- Switch on the high voltage power supply. Now the cathode is being heated.
- Slowly increase the anode voltage $U_A$ and observe the beam slowly increasing in brightness at the centre of the luminous screen.

- While $U_A$ < 5 kV is kept at a fixed value slowly increase the voltage at the capacitor plates $U_P$ and observe the change to the beam.
- Increase the current through the Helmholtz pair of coils $I$ just enough that the deflection on account of the electric field at the capacitor output is just compensated for (if necessary, reverse current flow).
- Maintain $U_P$ and $I$ at fixed values and vary $U_A$ and observe the changes to the beam.
- For various values of $U_A$ select $U_P$ and $I$ in such a way that the deflection on account of the electric and the magnetic fields just compensate, and enter the values in a table.

## Measuring example and evaluation

For various $U_A$ values the value pairs ($U_P$; $I$) were read off (see table) where compensation was achieved. The distance between the capacitor plates was $d$ = 5.5 cm.

From the equations 2 and 3 the values for the electric field **E** are obtained and for the magnetic field $B$. The number of windings of the coils is $N$ = 320, the average coil radius is $R$ = 6.7 cm. This allows the specific charge to be calculated using equation 1. The results are shown in the table below.

| $U_A$/kV | $U_P$/kV | $I$ / A | $E$ / kV/m | $B$/mT | $\dfrac{e}{m}/10^{11}\dfrac{\text{C}}{\text{kg}}$ |
|---|---|---|---|---|---|
| 3.0 | 4.0 | 0.38 | 55 | 1.6 | 1.9 |
| 4.0 | 4.0 | 0.33 | 55 | 1.4 | 1.9 |
| 5.0 | 4.0 | 0.30 | 55 | 1.3 | 1.8 |

This results in an average value for the specific charge of

$$\frac{e}{m} = 1.87 \cdot 10^{11} \frac{\text{V}}{\text{kg}} .$$

Literature value $\dfrac{e_0}{m_0} = 1.7588 \cdot 10^{11} \dfrac{\text{V}}{\text{kg}}$

## Note:

Even for optimum compensation the electron beam will not precisely run along the zero line. Outside the capacitor areas the magnetic field of the Helmholtz pair of coils is not zero but it slowly increases. In that area the magnetic field cannot be compensated for by the electric field from the capacitor plates and this leads to a small deviation of the electron beam from the zero line.

In the experiment the electrons are accelerated between a negatively charged cathode and an earthed anode (see circuit diagrams in figures 2 and 3). The capacitor plates are connected in such a way that the centre of the mica plate is at zero potential (see circuit diagram in figures 2 and 3). This means that between the anode and the mica plate no field is active and therefore there are no accelerating/braking forces on the electrons. The speed of the electrons when entering the capacitor plates can then be calculated from the acceleration voltage $U_A$. If the anode and the centre of the mica plate are at a different potential, the potential difference must also be taken into account when calculating the electron speed.